TITLE: MULTIDISCIPLINARY IMAGING OF ROCK PROPERTIES IN CARBONATE RESERVOIRS FOR FLOW-UNIT TARGETING

SEMI-ANNUAL TECHNICAL REPORT

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Abstract

Excellent progress has been made on all project objectives and goals. All tasks have been completed in the Phase 1 study area, the initial area of project focus. Primary elements of this work include the following: The stratigraphic architecture has been established through correlation of wireline logs guided by core and outcrop studies of facies and cyclicity. A porosity model has been developed that creates a basis for calculation of porosity for wells in the study area. Rock fabrics have been defined by sampling, analysis, and description of cores and used to create transforms for calculating permeability and oil saturation from porosity data. Finally, a preliminary 3-D model has been constructed that incorporates stratigraphic architecture, rock-fabric data, and petrophysical data. Reservoir volumetrics calculated from the model show that a very large fraction of the original oil in place remains.

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Introduction

The project is now well under way and has made significant progress toward all goals and objectives. This report describes the work accomplished on the project during months 5–10 of the project.

Executive Summary

The project is well under way, and significant progress was made during the last 6 months. Major accomplishments during the period were in (1) characterization of facies and cyclicity in subsurface cores and in outcrop, (2) construction of a stratigraphic framework, (3) definition of rock fabrics, (4) correlation of 3-D seismic data, and (5) construction of a reservoir model.

The first phase of the study is nearly completed. All Task 1 activities have been completed in the Phase 1 geographic area. Task 2 activities are continuing in the Phase 1 area. Task 1 efforts are now being conducted in the Phase 2 area and throughout the remainder of the project area. Task 4 activities are continuing throughout the field.

Initial construction of a 3-D reservoir model, a key step in the project, is complete for the Phase 1 study area. Although the 3-D model will continue to be refined as additional data become available, this model will ultimately serve as the basis for simulation and modeling of fluid flow in the reservoir because of the high quality of data available in the Phase 1 area.

Volumetrics calculated from this model are consistent with results from previous volumetric analyses in indicating that as much as 80 percent of the original oil in place (OOIP) has not been produced.

Experimental

Experimental work performed for the study during the past 6 months consists of the analysis of about 500 core plugs cut from conventional cores. These plugs were collected on a one-per-foot spacing and submitted to SCAL, Midland, Texas, for analysis of porosity and permeability. Data will be used in combination with descriptions and point counts from thin sections taken from plug ends to determine relationships between facies and petrophysical properties.

Results and Discussion

During the last 6 months of the project, we have made substantial additional progress on most project tasks, including Task 1, Construct Cycle Stratigraphic Framework, Task 2, Characterize and Model Rock Fabrics, and Task 4, Correlate and Model Rock Properties and 3-D Seismic Attributes.

Study of the Fullerton Clear Fork reservoir has been subdivided into three phases. Phases 1 and 2 focus, in turn, on two small areas of the reservoir; Phase 3 will involve study of the remaining parts of the reservoir and an integration of all three areas. The first phase of the study is nearly completed. All Task 1 activities have been completed in the Phase 1

geographic area. Task 2 activities are continuing in the Phase 1 area. Task 1 efforts are now being conducted in the Phase 2 area and throughout the remainder of the project area. Task 4 activities are continuing throughout the field.

Subtask 1.1 Describe Facies and Cyclicity in Cores.

Core description activities were completed for all six cored wells in the Phase 1 study area, a total of approximately 2,500 ft of core. More than 650 thin sections taken from these cores were also described to provide complementary facies data and information on rock fabrics. Work has now been extended to cores outside the Phase 1 study area. The current primary area of focus has been the eastern margin of the field, which, on the basis of regional setting and 3-D seismic data, is the highest accommodation part of the field area. Several important differences in the stratigraphic succession are apparent in this area of the field. First, Wichita tidal-flat facies thin significantly to the east. Underlying the thinned Wichita facies is a succession of normal marine carbonates containing abundant fusulinids and crinoids. Regional studies and 3-D data from the Fullerton field demonstrate that these rocks represent outer platform, clinoformal deposits of the Abo facies. The top of the Abo is typically marked by thick karst dissolution and infill profiles. Regional subsurface and outcrop studies demonstrate that this karsting developed during a major sea-level-fall event that marks the first Leonard sequence boundary (top of the L1 sequence). Overlying Wichita facies are transgressive tidal-flat deposits of the basal transgressive systems tract of sequence L2. Throughout most of the eastern part of the field, overlying lower Clear Fork deposits resemble those described in the Phase 1 area and define three subtidal-dominated, high-frequency sequences (HFS). Facies successions in the two lower HFS define 15 to 30 thick cycles composed of basal, outer ramp fusulinid wackestones and

upper, ramp-crest peloid grain-dominated packstones. Porosity and permeability are typically low in cycle-base fusulinid facies and high in cycle-top packstone facies. In the most basinward of the cores, this interval is characterized by debris-flow beds, indicating that locally within the field a sharp platform margin is developed from which platform debris was shed. Analysis of 3-D seismic data indicates that this sharp break in slope may be controlled by penecontemporaneous movement along reactivated Pennsylvanian faults. Interpretation of 3-D data combined with newly obtained 2-D data is thus crucial for accurate characterization of accommodation trends and possible fault-controlled depositional architecture and reservoir quality across the area.

Subtask 1.2 Describe Facies and Cyclicity in Outcrops.

Outcrop characterization of rocks equivalent to the lower Clear Fork and Wichita reservoir succession at Fullerton field continued in the Sierra Diablo of West Texas. During July, we focused on describing and characterizing the facies and sequence architecture along the platform margin in the Sierra Diablo. This succession may help provide analogs for the depositional styles encountered along the eastern, downdip margin of the field.

Subtask 1.3 Develop Wireline Correlation Framework.

Cycle-based log correlations of more than 80 wells in the Phase 1 study area have been completed for the lower Clear Fork (LCF) part of the reservoir section. Cycle thicknesses in the LCF range from 15 to 25 ft. In general, highest porosities are encountered in cycle tops. Correlations are based on a combination of gamma-ray and porosity log responses. Gamma-ray logs cannot be used independently for correlation because of the highly variable distribution of

uranium in the section. Correlations have also been established throughout the Phase 1 area for the Wichita section. However, because tidal-flat facies exhibit poor continuity and neither facies nor cycles are well tied to wireline log response, Wichita correlations are based largely on mineralogical variations. Although dominantly composed of dolomite, the Wichita section contains multiple continuous intervals of generally low porosity and permeability limestone that is readily identified on modern wireline log suites.

Subtask 2.1 Measure Petrophysical Properties in Core.

Approximately 500 core plugs were drilled from two cores in the Phase 1 study area at a spacing of one plug per foot. Samples were cut from each plug for thin-section preparation. Plugs were analyzed for conventional porosity and permeability by a standard oilfield service company. Thin sections are being used to tie rock-fabric descriptions to porosity and permeability measurements made from the plugs. Together these cores cover about 90 percent of the vertical reservoir succession. Comparisons of paired thin-section data and porosity and permeability data are key to defining rock-fabric types for the reservoir.

Subtask 2.2 Define and Characterize Rock Fabrics.

Approximately 650 thin sections from six cores in the Phase 1 area have been described to characterize rock-fabric types in the reservoir. This work indicates that the reservoir can be characterized by three rock-fabric types: Class 2 grain-dominated packstones (of the lower Clear Fork), moldic limestones (of the lower Clear Fork), and Class 3 tidal-flat mud-dominated packstones, wackestones, and mudstones (of the Wichita facies). These distinct rock-fabric types

have distinct transforms between porosity and permeability and oil saturation. Rock-fabric relationships will be used to calculate saturation and permeability from wireline porosity data for construction of the reservoir model.

Subtask 2.3 Collect Relative-Permeability and Capillary-Pressure Data.

This task has been deferred until rock fabrics are more accurately understood. We expect to select samples for measurement of relative-permeability and capillary-pressure data during the next 6 months of the project.

Subtask 2.4 Calibrate Wireline Logs for Rock-Fabric Identification.

Substantial progress has been made in using wireline log suites to define rock-fabric types. However, multiple porosity log curves are necessary to perform this calculation, and such log suites are rare in the Phase 1 area. Work continues to try to develop other wireline-based approaches to identification of both rock fabrics and mineralogy in the field.

Subtask 3.1. Collect Rock-Mechanics Data (Subcritical Crack Indices).

This task has been deferred until rock fabrics are better understood.

Subtask 3.2. Model Fracture Growth.

No significant fractures have been observed to date.

Subtask 4.1 Construct 3-D Seismic Attribute Model of Reservoir Porosity.

We continued to work on seismic attribute analysis and inversion of the 3-D seismic data. To reduce ambiguity in predicting log properties, we are testing a neural-network-assisted, multiattribute transform that will allow us to extract a high-resolution rock property volume from the 3-D data. This will aid in high-frequency sequence stratigraphic correlation and reservoir delineation in the area of 3-D coverage. Because porosity logs in the area have not been examined for accuracy, we are using acoustic logs for inversion work. Acoustic logs have been quality-checked and converted to velocity logs for 41 wells. A good-quality time-depth curve has been formulated for depth-to-time conversion of well logs.

ExxonMobil has supplied a limited number of 2-D lines for the field. These lines appear to be of very high quality and will be extremely valuable in extending 3-D seismic interpretations across the parts of the field where no 3-D seismic is valuable. ExxonMobil has agreed to provide an additional twenty 2-D lines for the study.

Subtask 4.2. Integrate 3-D Data with Rock-Fabric and Cycle-Stratigraphic Data.

This task has begun on a reconnaissance level only until corrected wireline logs are obtained from the southern part of the field where 3-D coverage exists. Initial comparison of seismic and wireline log data suggests a good relationship between amplitude and porosity development. We have also begun to examine the relationship between acoustic velocity and porosity.

Subtask 4.3. Distribute Reservoir Properties through Interwell Space.

A preliminary model of reservoir porosity was constructed for the Phase 1 area to examine geographic and stratigraphic trends in porosity distribution. This initial model has also been useful for revealing inconsistencies and errors in log data through the model area.

We have subsequently built and tested a fine-grid 3-D geologic model using 33 horizons and 85 wireline logs and containing porosity, permeability, and initial water saturation data. Permeability and water saturation were calculated using rock-fabric-based relationships. This 5.2-million cell model comprises 149 columns, 110 rows, and 320 layers. Porosity, permeability, and water saturation were modeled deterministically with a 2,000-ft search radius. In general, the lowermost sequence of the lower Clear Fork has the best porosity and permeability; the Wichita has good porosity but relatively lower permeability and porosity. The estimated OOIP for the Phase 1 area calculated from this model is 185 million stock-tank barrels (MMSTB). Because only 40 MMSTB has been produced to date from this area, 145 MMSTB, or about 80 percent of the OOIP, remains.

Additional Activity

We have nearly finished compiling historical production and completion data for the entire reservoir. Additionally, we have collected and compiled zone completion and test data for purposes of identifying flow through the reservoir. About half the injection surveys and all of the production logs have been transcribed. Currently, efforts are under way to load the build-up and fall-off pressure data. Once those data are loaded, we will start on the rest of the injection survey data. Apparent water resistivity (Rwa) and apparent water saturation curves have been calculated to aid in determining which zones in the wells have undergone water breakthrough.

Operator Contact

Staff from ExxonMobil traveled to Austin to meet with Bureau Fullerton team members. In attendance from ExxonMobil were Terry Anthony, lead field engineer, Dave Smith, geologist, Jonas Gournay, geologist, Mike Williams, engineer, Damon Buffington, U.S. West engineering supervisor, and Sam Leininger, U.S. West geological advisor. Also in attendance was Tim Hunt, The University of Texas System geologist. Bureau staff present were Eric Potter, Mark Holtz, Rebecca Jones, Jeff Kane, Jerry Lucia, Fred Wang, Hongliu Zeng, and Steve Ruppel. Dan Ferguson, DOE project specialist, was unable to attend the meeting.

Among other aspects of the study presented, the Bureau provided ExxonMobil with an estimate of original and remaining oil in the Phase 1 model area. These calculations suggest that the area originally contained 185 MMSTB (OOIP). Only 40 MMSTB has been produced to date, indicating that 145 MMSTB, or about 80 percent of the OOIP, remains. When one considers the fact that the Phase 1 model area is one of the most completely developed parts of the field, these data suggest that a very large target resource remains in the field as a whole.

ExxonMobil staff indicated that they would like to have the Bureau continue to improve the model being created for the Phase 1 area so that it can be used for CO_2 injection modeling and simulation. It was agreed that this area is the best for characterizing past and present fluid-flow patterns in the field; thus, maximum effort should be placed on making this model the best it can be. Accordingly, the Bureau will continue to perfect this model using additional core data and revised log analysis techniques. Damon Buffington, U.S. West engineering supervisor for ExxonMobil, indicated that the model will be used as a key basis for developing and proposing a large-scale field exploitation plan to ExxonMobil management.

Conclusions

We have continued to make good progress on the project during the past 6 months. Most initial causes for delays have been overcome. Most tasks have been completed for the Phase 1 geographic study area, including (1) establishment of the stratigraphic architecture, (2) identification and characterization of rock fabrics, (3) development of transforms for calculation of permeability and saturation from porosity, and (4) construction of 3-D reservoir model. Good progress has also been made in using the 3-D seismic data to define underlying structural controls on reservoir development and to image porosity distribution in the reservoir.

Although the 3-D model will continue to be refined as additional data become available, this model will ultimately serve as the key for simulation and modeling of fluid flow in the reservoir because of the high quality of data available in the Phase 1 area. Preliminary volumetric calculations from the model indicate that as much as 80 percent of the OOIP in the reservoir remains unproduced. Reservoir characterization of the entire reservoir, including the imaging of rock fabrics and reservoir architecture, and fluid-flow modeling and simulation will provide key insights into the best practices for improved recovery of this huge resource.